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Basic Considerations of Densitometer Adjustment and Calibration

Richard E. Swing

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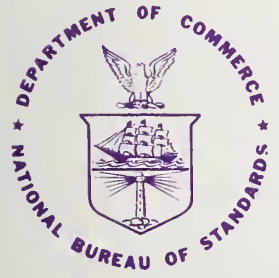
Interim Report



U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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BASIC CONSIDERATIONS OF DENSITOMETER ADJUSTMENT AND CALIBRATION

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Interim Report

U. S. DEPARTMENT OF COMMERCE, Secretary
NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

This document has been prepared as part of the program to upgrade and improve the density-measurement capability at NBS through research in the Optics and Micrometrology Section of the Optical Physics Division. It is the first of several that will be released in this subject-area, and will occasionally undergo revision and expansion as the program develops. At the end of the program, a complete NBS report on Densitometry and related matters will be prepared and published.

SCOPE

The considerations of this note are limited to instruments which measure large-area, or macro-density (as opposed to microdensity) and to those devices in which the geometry of illumination and light-collection are permanently fixed within the system. Further, we shall restrict our discussion to transmission density (although many of the principles of adjustment and calibration will apply to reflection density measurement), and limit the type of density measured to that known as diffuse (or singly diffuse).

STANDARDS

There are two types of standards that must be considered. Documentary standards are written procedures or methods which define the quantities to be measured, specify the conditions under which measurements will be valid and useful, and provide guidance in the interpretation of results. Physical measurement standards provide a means for transferring measurements of the same quantity from a "standard" instrument to an "operational" instrument. The physical measurement standard is used to provide an absolute measurement of a quantity that is repeatable, conforms to an accepted documentary standard and whose precision of measurement is certifiable. The physical measurement standard is then used to bring an instrument's response into conformity with another's. This guarantees that the instrument output is identical (in the mathematical sense), or related, to that which was in effect when the physical measurement standard was calibrated. Thus, the instrument response is such that when measurements are subsequently made on other materials, the results are said to be "traceable" to the calibrating source, and in principle, can be reproduced on the source's measurement instrument.

In the case of transmission density, the documentary standard is ANSI Standard PH2.19-1959, "American Standard Diffuse Transmission Density," and the physical measurement standard is a step tablet calibrated at the National Bureau of Standards.

NBS TRANSMISSION DENSITY PHYSICAL STANDARDS

Diffuse density and its measurement are governed by the cited ANSI documentary standard. This standard is currently under revision by ANSI Subcommittee PH2.28. The two techniques used at NBS for calibration of physical measurement standards for optical density are in full conformance with the provisions of the documentary standard. Primary density standard calibrations are achieved through an inverse-square technique. This method provides density measurements with a certifiable precision of 0.005 density units or 1/2-percent, whichever

is larger. The calibration of a secondary, less-precise physical measurement standard is accomplished with a densitometer that itself has been calibrated with a NBS primary density standard, and used with a geometry and procedure equivalent to those specified for ANSI measurements of diffuse density. This method provides density measurements with a certifiable precision of 0.01 density units or 1-percent, whichever is larger. All densities measured at NBS are characterized as diffuse (visual) density, a spectral type of diffuse density that relates to the average normal human eye adapted to photopic vision.

NBS routinely provides calibrated step tablets (21 steps, on a 3.5 x 25 cm tablet) through the Office of Standard Reference Materials. SRM-1009 has a density range of 0 to 3.0, while SRM-1008 increases the upper limit to 4.0. The precision in both cases is 0.01 density units or 1 percent, whichever is larger. These tablets are also suitable for primary standards, but must be calibrated on the inverse-square instrument to the cited precision. Primary standards are only provided on request, because the need is less and because they are more than ten times as costly as the secondary standards.

Occasionally, NBS will calibrate user-submitted step tablets. However, when these are soiled, scratched, fingerprinted or otherwise blemished, or contain non-uniform densities within the various steps NBS will return them uncalibrated. NBS prefers to provide the basic tablet for calibration. This results from an important concern of diffuse density measurement. When the densitometer is configured in conformance with ANSI Standard PH2.19-1959, density so measured is independent of the material comprising the step tablet. Scattering or other density-varying attributes of materials do not enter into this measurement. However, densitometers that do not conform to the standard configuration will give varying responses with different materials, and NBS strongly suggests that instruments be brought into conformity to eliminate this difficulty.

PRACTICAL DENSITOMETER ADJUSTMENT

The purpose of the calibrated step tablets, consistent with the role of physical measurement standards, is the calibration of normal operational instrument response in terms of diffuse (visual) density. This is necessary for several reasons.

Each densitometer, no matter the manufacturer, design, configuration or mode of operation, obtains an indication of illuminance in the aperture of his detector system that results from the passage of light through the sample. The mode of indication varies. In some instruments, it is a meter-needle read against a scale; in others it may be digitized. Whatever it is, the

manufacturer, to provide means whereby the instrument can be reset to obtain reproducible results, supplies an adjustment procedure.

This adjustment procedure commonly adjusts the needle reading (or other output indication) at a density value of zero and at one other density value much higher on the scale. Having done this, it is not uncommon to check a third point, although it is not necessary. It is only necessary to be able to reproduce this adjustment, at the two values, whenever it is required.

At this instrument setting, the densitometer has a response determined by the photometric measurement system. It may be linear, it may not be. In a meter-needle/density scale system the system response is assumed to follow the scale markings; when they are equally-spaced, the response is assumed to be linear. The logarithmic amplifiers in the device are usually of high quality, and the output is generally linear over a reasonable range. But straight-line response from the origin to densities in excess of 3.0 depends on having a logarithmic converter that reads accurately over an input voltage range of 1000:1. This is difficult to do without correcting adjustments. It is particularly true of instruments fabricated on a production basis. The dial (or other readout device) and electronic circuits are designed and installed according to nominal specifications, but like the "average man," are not expected to exist as exactly specified for all instruments, for all time. But perfect straight-line response is not really necessary; variability can be compensated by the simple procedure of calibration.

PRACTICAL DENSITOMETER CALIBRATION

Calibration of the instrument against a physical measurement standard modifies the assumed (or indicated) response so that the instrument produces correct values of diffuse density. Calibration is effected by first adjusting the densitometer according to the procedure discussed previously. After adjustment, the physical measurement standard is then inserted into the measuring system and each step read and recorded.* This gives a set of values of instrument reading corresponding to the set of diffuse density values on the standard. The calibration is summarized in the form of a plotted curve of Instrument Reading vs. Diffuse Density, or in a Calibration Table (discussed in the next Section). If the instrument

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*As with all such measurements, these are repeated as often as necessary to establish a good statistical base, so that the user has sufficient confidence in the results to subject them to subsequent analysis and use.

conforms to ANSI standard geometry and illumination, and the step tablet used to calibrate it has values of diffuse density (measured in the manner directed by the documentary standard), then all readings subsequently made with the instrument are characterized as diffuse density (using the calibration curve or table), within the precision of the step tablet used for the calibration and the measurement tolerances of the instrument data readout.

Thus, in principle, the need for building the "perfect" or "near-perfect" densitometer does not exist. Any reasonable response can be compensated through calibration. Practically, it is convenient not to have to use a curve or table to correct instrument readings; the saving in time alone is often sufficient to repay the added cost for accuracy in density measurement. But even the best instruments require calibration: it checks system response, determines error bounds, and provides a "traceability" in the measurement procedure.

Calibration of densitometers is particularly essential in instruments that are not strictly configured to measure diffuse density. A prime example of this is the microdensitometer which measures a specular density that varies with the numerical apertures of the optics. Macrodensitometers that do not meet ANSI specifications for diffuse density must also undergo thorough and repeated calibration to reduce readings to diffuse density values. The frequency of calibration and the precision of the standard used depend to a great extent on the purpose of the instrument. In many instances, commercial interests do not require calibration curves or tablets, but merely insist that the instrument read to within some specified density range for each step on the calibration tablet. A typical value is ± 0.05 density units. When a periodic check against the physical measurement standard indicates departure of density values beyond these error bounds, the instrument is serviced. For inspection, acceptance-testing or sorting operations, the application of such error bounds is adequate. However, for precision use (where subsequent calculations will be based on the characteristic curve of the material, for example) calibration curves or tables are a necessity.

CALIBRATION DISPLAY AND USE

Calibration displays should reflect the precision of measurement, be accurately drawn or summarized and be convenient to use. Ordinarily, most densitometers can read to 0.02 density units (scale divisions); some can visually interpolate to 0.01 density units quite accurately. Most digital displays have a least-count of 0.01. Thus, if the operator is going to read density to the nearest 0.01 unit, his calibration display should reflect that precision. If he chooses to

plot his calibration, he should not be required to interpolate between lines to obtain his corrections. This stems from the problem of eye fatigue and loss of time in tracking between lines from the abscissa up to the curve - then over to the ordinate value. For densities on the physical standard up to, say 4.0, 400 separate and distinct lines on his graph paper are required, in both dimensions. For nearly all cases, this requires a sheet of paper that is prohibitively large, although by halving (and using the spaces between lines, with its attendant interpolation problem), the paper size can sometimes be reduced to manageability. Accuracy will be affected by the ability to use a draftsman's spline (French Curve) in connecting the points to make a smooth curve. Unless a great deal of care is exercised, the precision inherent both in the calibration and the physical measurement standard will disappear, and the precision implied by the abscissa and ordinate graduations will be illusory.

Probably the most accurate way of displaying calibration information is in a Calibration Table. This is a listing of Instrument Reading versus Diffuse Density for the entire range of the instrument calibration. The values of Instrument Reading should reflect the smallest value (precision) the operator intends to measure. If he will read to 0.01 density units, then the table should increment Instrument Reading by that unit. In use, it is a simple matter to look up the Instrument Reading in the listing and its corresponding value of Diffuse Density. There is no problem of lines to follow, and the contiguous pairing of the two numbers simplifies use. The major problem lies in the preparation of the table.

Ordinarily, 22 points are available from the calibration (including the point 0,0). The remainder of the values, those in-between the calibration points must be calculated. The calculation of 400 of more points, using any of the various algorithms provided in classical texts on numerical analysis will be prohibitive in time unless carried out on a digital computer. However, once reduced to a program for the computer, the computation and printing of the table is vastly simplified, and gives the calibration quickly and efficiently. Futhermore, as the instrument changes its performance (as it "wears-in"), new calibration tables can be computed and printed with very little additional expenditure of time and effort. Updating the calibration ceases to be a major undertaking.

COMPUTER PROGRAM FOR CALIBRATION TABLES

A computer program has been prepared for use at NBS by the Optics and Micrometrology Section, for the express purpose of calculating densitometer calibration tables. This program as shown in the listing of the Appendix will handle densities up to 6.0 (with an expansion of

two arrays, this limit can be extended). The program name is DENCAL; a typical print-out is shown in the Appendix, following the listing.

DENCAL calculates the density values between calibration points through a technique of spline-fitting, a method completely analogous to using a French Curve to smooth points into a continuous curve on a graph. Details of general spline-fitting can be found in Ralph H. Pennington, Introductory Computer Methods and Numerical Analysis, 2d Ed., (The MacMillan Company, Toronto, Canada, 1970), pp. 445-452. Every calibration point lies on the "curve," and it is as accurate as any of the standard interpolation formulas.

The program is written in BASIC language, and used at NBS through a teletype unit with a commercial time-sharing computer. BASIC, in form and content, is equivalent to elementary FORTRAN and can quickly be converted to that language if a user so requires. The Print and Format statements for setting up the tables have purposely been written with conversion to FORTRAN in mind.

Data Input for DENCAL:

The following procedure should be used for entering data in DENCAL:

1) On line 900, enter the number of pairs of points to be used in the calibration, and which will listed in lines following that entry.

2) Following line 900, enter data in the form of pairs of points (paired as INSTRUMENT READING, DIFFUSE DENSITY), in increasing order, including the lower instrument adjustement end-point, 0,0. See lines 910 and subsequent in the listing of the Appendix for a specific example.

3) DENCAL will increment the Instrument Reading column of the table by whatever value the user specifies. In the cited listing, it is specified as 0.01, and this should be used for those instruments with a real or implied precision of 0.01. Enter the desired value on line 920, or do not patch-in if the one already there is correct.

Output from DENCAL:

The program prints two column-pairs per page; the columns contain 50 pairs of values each. Sufficient spacing is provided in the program's print-outs so that each page can be trimmed to an 8-1/2 x 11 inch size for insertion into standard-size notebooks. The input

(calibration) data are not printed-out in a separate group. However, the actual points can be checked against the table after preparation; the spline-fit procedure will always have the basic calibration points in the table.

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A punched tape containing DENCAL is available from the Optics and Micrometrology Section for loan to those interested in using the program. Direct requests for this tape or for additional information to: R. E. Swing, A-123 Metrology Building, National Bureau of Standards, Washington, D. C., 20234.

APPENDIX

DENCAL:

A Computer Program for Preparing Densitometer Calibration Tables

```
001 * RICHARD E. SWING, PROGRAM: DENCAL
002 *
003 * THIS PROGRAM PREPARES A CALIBRATION TABLE THAT RELATES
004 * INSTRUMENT READINGS TO A CALIBRATED PHYSICAL STANDARD.
005 * THE TABLE STEPS INSTRUMENT READING ACCORDING TO THE VALUE
006 * ON LINE 920.  CHANGE FORMAT STATEMENTS ON LINES 502,506
007 * 525,528,541,543,547,560 AND 570 AS REQUIRED FOR THE SPECIFIC
008 * INSTRUMENT, AND PATCH-IN THE APPROPRIATE DATA ON LINES
009 * 910 AND SUBSEQUENT.  CHANGE DATA LINE 900 TO REFLECT THE
010 * NUMBER OF PAIRS OF POINTS.  DATA MUST BE LISTED IN INCREAS-
011 * ING ORDER, IN PAIRS, INSTRUMENT READING FIRST IN EACH PAIR.
012 *
013 DIM A(30,3),C(4,30)
014 DIM G(601),H(601)
015 DIM X(30),Y(30),Z(30),B(30),D(30),E(30),P(39)
016 FOR J = 1 TO 10
017 PRINT
018 NEXT J
020 GOSUB 540      'PRINT TABLE HEADING'
024 READ M
026 FOR I = 1 TO M          'INPUT THE DATA'
027 READ X(I),Y(I)
028 NEXT I
029 READ C
030 B = (X(M)-X(1))/C
031 IF B > 601 GO TO 601
032 M1 = M-1             'CALCULATE FIT-COEFFICIENTS'
034 FOR K = 1 TO M1
036 D(K) = X(K+1)-X(K)
038 P(K) = D(K)/6
040 E(K) = (Y(K+1)-Y(K))/D(K)
042 NEXT K
044 FOR K = 2 TO M1
046 B(K) = E(K) - E(K-1)
048 NEXT K
050 A(1,2) = -1.0-D(1)/D(2)
052 A(1,3) = D(1)/D(2)
054 A(2,3) = P(2)-P(1)*A(1,3)
056 A(2,2) = 2*(P(1)+P(2))-P(1)*A(1,2)
058 A(2,3) = A(2,3)/A(2,2)
060 B(2) = B(2)/A(2,2)
062 FOR K = 3 TO M1
064 A(K,2) = 2*(P(K-1)+P(K))-P(K-1)*A(K-1,3)
066 B(K) = B(K)-P(K-1)*B(K-1)
068 A(K,3) = P(K)/A(K,2)
070 B(K) = B(K)/A(K,2)
072 NEXT K
074 Q = D(M-2)/D(M-1)
076 A(M,1) = 1 + Q + A(M-2,3)
078 A(M,2) = -Q - A(M,1)*A(M-1,3)
080 B(M) = B(M-2)-A(M,1)*B(M-1)
082 Z(M) = B(M)/A(M,2)
084 M2 = M-2
086 FOR I = 1 TO M2
088 K = M-I
090 Z(K) = B(K)-A(K,3)*Z(K+1)
092 NEXT I
```

```
094 Z(1) = -A(1,2)*Z(2)-A(1,3)*Z(3)
096 FØR K = 1 TØ M1
098 Q = 1/(6*D(K))
100 C(1,K) = Z(K)*Q
102 C(2,K) = Z(K+1)*Q
104 C(3,K) = (Y(K)/D(K))-(Z(K)*P(K))
106 C(4,K) = (Y(K+1)/D(K))-(Z(K+1)*P(K))
108 NEXT K
114 FØR J = 1 TØ B+1          'CALCULATE TABLE'
116 G(J) = X(1)+(J-1)*C
122 IF (G(J)-X(1)),146,124,128
124 H(J) = Y(1)
126 GØ TØ 148
128 K = 1
130 IF (G(J)-X(K+1)),140,132,136
132 H(J) = Y(K+1)
134 GØ TØ 148
136 K = K+1
138 IF (G(J)-X(M)),130,146,146
140 H(J) = (X(K+1)-G(J))*(C(1,K)*((X(K+1)-G(J))**2)+C(3,K))
142 H(J) = H(J)+(G(J)-X(K))*(C(2,K)*((G(J)-X(K))**2)+C(4,K))
143 GØ TØ 148
146 H(J) = Y(M)
148 NEXT J
149 PRINT
150 PRINT             'PRINT-ØUT HEADINGS AND ØPTIØNS'
151 K = 0
152 IF (B+1) < 100 GØ TØ 216
153 GØSUB 500
154 FØR J = ((2*K*50)+1) TØ ((50*(2*K+1))+1)
160 PRINT,560,G(J),H(J),G(J+50),H(J+50)
170 NEXT J
180 FØR J = 1 TØ 10
182 PRINT
183 NEXT J
190 IF ((50*(2*K+3)+51)-(B+1)),195,195,205
195 K = K+1
200 GØ TØ 153
205 IF (B+1) > (50*(2*K+1)+51) GØ TØ 220
210 FØR J = 1 TØ 10
212 PRINT
214 NEXT J
215 GØ TØ 999
216 K = -1
217 IF (B+1) < 50 GØ TØ 250
218 GØ TØ 222
220 IF (B+1) < (100*(K+1)+51) GØ TØ 250
222 GØSUB 500
224 FØR J = (2*(K+1)*50+1) TØ ((B+1)-50)
226 PRINT,560,G(J),H(J),G(J+50),H(J+50)
230 NEXT J
232 FØR J = (B+1)-49 TØ (50*(2*K+3)+1)
234 PRINT,570,G(J),H(J)
236 NEXT J
```

```
240 FØR J = 1 TØ 10
242 PRINT
244 NEXT J
245 GØ TØ 999
250 GØSUB 522
252 FØR J = (2*(K+1)*50+1) TØ (B+1)
254 PRINT,570,G(J),H(J)
256 NEXT J
260 FØR J = 1 TØ (60+2*(K+1)*50-B)  'EXTRA SPACES, LAST PAGE'
262 PRINT
264 NEXT J
265 GØ TØ 999
500 PRINT,502       'TWØ-CØLUMN HEADING SUBRØUTINE'
502 FMT X5,"INSTRUM",X5,"DIFFUSE",X15,"INSTRUM",X5,"DIFFUSE"
504 PRINT,506
506 FMT X5,"READING",X5,"DENSITY",X15,"READING",X5,"DENSITY"
508 PRINT
509 RETURN
522 PRINT,525       'SINGLE-CØLUMN HEADING SUBRØUTINE'
525 FMT X5,"INSTRUM",X5,"DIFFUSE"
527 PRINT,528
528 FMT X5,"READING",X5,"DENSITY"
529 PRINT
530 RETURN
540 PRINT,541       'TABLE-HEADING SUBRØUTINE'
541 FMT "DENSITØMETER CALIBRATIØN TABLE"
542 PRINT,543
543 FMT "XYZ CØMPANY LABØRATØRY, INSTRUMENT #7"
545 PRINT "DATE:      ";
546 PRINT,547,TIM(1),TIM(2),TIM(3)
547 FMT I3,"/",I3,"/",I3
548 PRINT
549 PRINT
550 RETURN
555 * FØRMAT STATEMENTS
560 FMT X3,F8.2,X4,F8.2,X14,F8.2,X4,F8.2
570 FMT X3,F8.2,X4,F8.2
600 * WARNING STATEMENT ABØUT ARRAY SIZE
601 PRINT "THE CALCULATIØNS WILL REQUIRE MØRE ARRAY CAPACITY."
602 PRINT "INCREASE THE DIMENSIØNS ØF G( ) AND H( ),"
603 PRINT,604,INT(B+1)
604 FMT "ØN LINE 014, TØ",I5,",","," AND RUN AGAIN."
606 PRINT
607 GØ TØ 999
899 * DATA SECTIØN
900 DATA 20
910 DATA 0,0,0.04,0.055,0.21,0.23,0.42,0.43,0.64,0.64
912 DATA 0.83,0.84,1.04,1.05,1.23,1.25,1.45,1.45,1.65,1.65
914 DATA 1.86,1.86,2.04,2.05,2.22,2.25,2.43,2.465,2.65,2.68
916 DATA 2.86,2.88,3.05,3.045,3.22,3.245
918 DATA 3.42,3.365,3.64,3.68
920 DATA 0.01
999 END
```

DENSITØMETER CALIBRATIØN TABLE
XYZ CØMPANY LABØRATØRY, INSTRUMENT #7
DATE: 2/ 25/ 75

INSTRUM READING	DIFFUSE DENSITY	INSTRUM READING	DIFFUSE DENSITY
.00	.00	.50	.50
.01	.01	.51	.51
.02	.03	.52	.52
.03	.04	.53	.53
.04	.05	.54	.54
.05	.07	.55	.55
.06	.08	.56	.56
.07	.09	.57	.57
.08	.10	.58	.58
.09	.11	.59	.59
.10	.12	.60	.60
.11	.13	.61	.61
.12	.14	.62	.62
.13	.15	.63	.63
.14	.16	.64	.64
.15	.17	.65	.65
.16	.18	.66	.66
.17	.19	.67	.67
.18	.20	.68	.68
.19	.21	.69	.69
.20	.22	.70	.70
.21	.23	.71	.71
.22	.24	.72	.72
.23	.25	.73	.73
.24	.26	.74	.75
.25	.27	.75	.76
.26	.28	.76	.77
.27	.29	.77	.78
.28	.30	.78	.79
.29	.31	.79	.80
.30	.32	.80	.81
.31	.32	.81	.82
.32	.33	.82	.83
.33	.34	.83	.84
.34	.35	.84	.85
.35	.36	.85	.86
.36	.37	.86	.87
.37	.38	.87	.88
.38	.39	.88	.89
.39	.40	.89	.90
.40	.41	.90	.91
.41	.42	.91	.92
.42	.43	.92	.93
.43	.44	.93	.94
.44	.45	.94	.95
.45	.46	.95	.96
.46	.47	.96	.97
.47	.48	.97	.98
.48	.49	.98	.99
.49	.50	.99	1.00
.50	.50	1.00	1.01

INSTRUM READING	DIFFUSE DENSITY	INSTRUM READING	DIFFUSE DENSITY
1.00	1.01	1.50	1.50
1.01	1.02	1.51	1.51
1.02	1.03	1.52	1.52
1.03	1.04	1.53	1.53
1.04	1.05	1.54	1.54
1.05	1.06	1.55	1.55
1.06	1.07	1.56	1.56
1.07	1.08	1.57	1.57
1.08	1.09	1.58	1.58
1.09	1.10	1.59	1.59
1.10	1.11	1.60	1.60
1.11	1.12	1.61	1.61
1.12	1.14	1.62	1.62
1.13	1.15	1.63	1.63
1.14	1.16	1.64	1.64
1.15	1.17	1.65	1.65
1.16	1.18	1.66	1.66
1.17	1.19	1.67	1.67
1.18	1.20	1.68	1.68
1.19	1.21	1.69	1.69
1.20	1.22	1.70	1.70
1.21	1.23	1.71	1.71
1.22	1.24	1.72	1.72
1.23	1.25	1.73	1.73
1.24	1.26	1.74	1.74
1.25	1.27	1.75	1.75
1.26	1.28	1.76	1.76
1.27	1.29	1.77	1.77
1.28	1.30	1.78	1.78
1.29	1.31	1.79	1.79
1.30	1.32	1.80	1.80
1.31	1.32	1.81	1.81
1.32	1.33	1.82	1.82
1.33	1.34	1.83	1.83
1.34	1.35	1.84	1.84
1.35	1.36	1.85	1.85
1.36	1.37	1.86	1.86
1.37	1.38	1.87	1.87
1.38	1.39	1.88	1.88
1.39	1.40	1.89	1.89
1.40	1.40	1.90	1.90
1.41	1.41	1.91	1.91
1.42	1.42	1.92	1.92
1.43	1.43	1.93	1.93
1.44	1.44	1.94	1.94
1.45	1.45	1.95	1.95
1.46	1.46	1.96	1.96
1.47	1.47	1.97	1.97
1.48	1.48	1.98	1.98
1.49	1.49	1.99	2.00
1.50	1.50	2.00	2.01

INSTRUM READING	DIFFUSE DENSITY	INSTRUM READING	DIFFUSE DENSITY
2.00	2.01	2.50	2.53
2.01	2.02	2.51	2.54
2.02	2.03	2.52	2.55
2.03	2.04	2.53	2.56
2.04	2.05	2.54	2.57
2.05	2.06	2.55	2.58
2.06	2.07	2.56	2.59
2.07	2.08	2.57	2.60
2.08	2.09	2.58	2.61
2.09	2.11	2.59	2.62
2.10	2.12	2.60	2.63
2.11	2.13	2.61	2.64
2.12	2.14	2.62	2.65
2.13	2.15	2.63	2.66
2.14	2.16	2.64	2.67
2.15	2.17	2.65	2.68
2.16	2.18	2.66	2.69
2.17	2.20	2.67	2.70
2.18	2.21	2.68	2.71
2.19	2.22	2.69	2.72
2.20	2.23	2.70	2.73
2.21	2.24	2.71	2.74
2.22	2.25	2.72	2.75
2.23	2.26	2.73	2.76
2.24	2.27	2.74	2.77
2.25	2.28	2.75	2.78
2.26	2.29	2.76	2.79
2.27	2.30	2.77	2.80
2.28	2.31	2.78	2.81
2.29	2.32	2.79	2.82
2.30	2.33	2.80	2.83
2.31	2.34	2.81	2.84
2.32	2.36	2.82	2.85
2.33	2.37	2.83	2.85
2.34	2.38	2.84	2.86
2.35	2.39	2.85	2.87
2.36	2.40	2.86	2.88
2.37	2.41	2.87	2.89
2.38	2.42	2.88	2.90
2.39	2.43	2.89	2.90
2.40	2.44	2.90	2.91
2.41	2.45	2.91	2.92
2.42	2.46	2.92	2.93
2.43	2.47	2.93	2.94
2.44	2.47	2.94	2.94
2.45	2.48	2.95	2.95
2.46	2.49	2.96	2.96
2.47	2.50	2.97	2.97
2.48	2.51	2.98	2.98
2.49	2.52	2.99	2.99
2.50	2.53	3.00	2.99

INSTRUM READING	DIFFUSE DENSITY
3.00	2.99
3.01	3.00
3.02	3.01
3.03	3.02
3.04	3.03
3.05	3.04
3.06	3.06
3.07	3.07
3.08	3.08
3.09	3.09
3.10	3.10
3.11	3.12
3.12	3.13
3.13	3.14
3.14	3.16
3.15	3.17
3.16	3.18
3.17	3.19
3.18	3.20
3.19	3.21
3.20	3.23
3.21	3.24
3.22	3.24
3.23	3.25
3.24	3.26
3.25	3.27
3.26	3.28
3.27	3.28
3.28	3.29
3.29	3.30
3.30	3.30
3.31	3.31
3.32	3.31
3.33	3.32
3.34	3.32
3.35	3.33
3.36	3.33
3.37	3.34
3.38	3.34
3.39	3.35
3.40	3.35
3.41	3.36
3.42	3.36
3.43	3.37
3.44	3.38
3.45	3.39
3.46	3.39
3.47	3.40
3.48	3.41
3.49	3.42
3.50	3.43

INSTRUM READING	DIFFUSE DENSITY
3.50	3.43
3.51	3.44
3.52	3.45
3.53	3.47
3.54	3.48
3.55	3.49
3.56	3.51
3.57	3.53
3.58	3.55
3.59	3.56
3.60	3.58
3.61	3.61
3.62	3.63
3.63	3.65
3.64	3.68

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16. ABSTRACT (*A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.*)

The adjustment and calibration of a densitometer are considered. This is accomplished through the use of physical measurement standards with a procedure appropriate for the instrument, and brings the instrument response in line with measurements traceable to NBS. The difference between primary and secondary physical measurement standards for diffuse (visual) density is discussed. A calibration table is suggested for best use of the instrument and a computer program (BASIC language) is provided that will calculate and print a table relating instrument reading to diffuse (visual) density.

17. KEY WORDS (*six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons*) **Calibration; Calibration table; densitometer; Densitometry; Optical density; Optical density standard**

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